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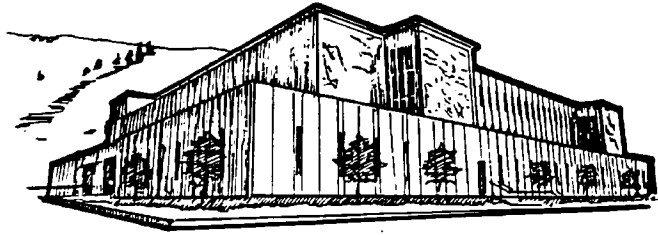
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**Montana**



**TO REUR, RECD, OR SIMPLY NAL:  
A COMPARISON OF THREE METHODS OF  
ORDERING 2 cc COUPLER GAIN FOR  
HEARING AIDS**

By

Linda Jean Scarlett-Hauck

B.Ed., University of Saskatchewan, 1966

Presented in partial fulfillment of the requirements


for the degree of

Master of Communication Sciences and Disorders

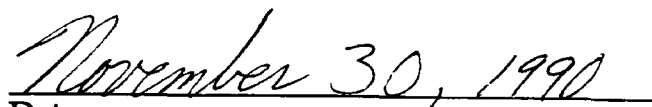
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Scarlett-Hauck, Linda J., M.C.S.D., December 1990

Communication Sciences  
and Disorders

**To REUR, RECD, or Simply NAL: A Comparison of Three  
Methods of Ordering 2 cc Coupler Gain for Hearing Aids  
(36 pp.)**

Director: Michael K. Wynne, Ph.D.



Nearly 80 percent of hearing aids now dispensed are custom in-the-ear hearing aids. A satisfactory method of specifying the desired electroacoustic characteristics for these hearing aids to the manufacturer is required. Thirty-six patients fit with forty-nine in-the-ear hearing aids participated in this study to determine whether three different methods of specifying 2 cc coupler gain to the manufacturer would prescribe similar gain across frequencies for a given hearing loss. The three methods investigated were the revised National Acoustic Laboratory's procedure (Byrne & Dillon, 1986), a NAL plus real ear unaided response (REUR) corrections method, and a new formula described by Punch, Chi, and Patterson (1990) which incorporated use of the individual's REUR and real ear coupler difference (RECD). The results of this study indicated that the NAL + REUR corrections method prescribed less gain than either of the other two methods. The Punch et al. formula prescribed more gain than either of the two other methods, particularly in the high frequencies. For patients with a high-frequency hearing loss, this method may provide the required amount of insertion gain in the high frequencies.

## ACKNOWLEDGEMENTS

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# CHAPTER I

## INTRODUCTION

In-the-ear hearing aids now account for 78% of the total number of hearing aids sold in the United States (Cranmer, 1990). These hearing aids are custom-made by the manufacturer and are designed to fit into the concha of the individual's ear. Relatively few adjustments in the acoustic output of these hearing aids can be made by the hearing aid dispenser. When ordering custom-made hearing aids from the manufacturer, therefore, the hearing aid dispenser must specify the appropriate electroacoustic characteristics based on the desired real ear insertion gain or frequency response for a particular individual.

Mueller (1989) suggested that a hearing instrument dispenser can use one of several methods to specify the desired electroacoustic characteristics for a hearing aid from the manufacturer. The dispenser can send an audiogram with the order and allow the manufacturer to choose the frequency response for the hearing aid, or the dispenser can order a matrix from the manufacturer's frequency response matrix book. An alternative for the dispenser is to use a prescriptive formula to determine desired gain, with or without correction factors to individualize the formula. If the hearing aid is being fit according to a prescriptive formula, Mueller stated that it may be necessary to specify the desired gain at each frequency, preferably in terms of full-on gain 2 cc coupler values. This study investigated three methods of specifying 2 cc coupler gain to the manufacturer to determine whether there is a similarity in the

hearing aids ordered by each method for a given hearing loss. The three methods investigated were the revised National Acoustic Laboratory's procedure (Byrne & Dillon, 1986), the NAL Revised procedure with corrections for the individual's external ear acoustics or real ear unaided response, and a new procedure by Punch, Chi, and Patterson (1990) incorporating the individual's real ear unaided response and real ear-to-coupler differences.

The latter two methods utilized real ear measurements obtained with a probe tube microphone system. Terminology for real ear measurements has not been standardized, however, the ANSI S3.80 working committee has suggested terminology and these terms will be used throughout this paper (Mueller, 1990; Punch, Chi & Patterson, 1990; Schweitzer, Sullivan, Beck, & Cole, 1990). These terms are defined in Table 1.

### **Real Ear Coupler Differences and the Use of Correction Values**

The 2 cc coupler differs from the real ear in impedance, volume, and diffraction (Libby & Westermann, 1988). These differences subsequently result in changes in the frequency response measured in the real ear and in the coupler. Killion and Monser (1980) pointed out that as early as 1972, Sachs and Burkhard found an increase in actual ear drum pressure over the 2 cc coupler pressure of roughly 3.5 dB at low frequencies, 5 dB at 1 kHz, 10 dB at 3 kHz, and 15 dB kHz at 6 kHz for a behind-the-ear hearing aid. More recently, research at Frye Electronics refined real ear coupler differences.

**Table 1. Glossary of real ear terminology.**

---

**Coupler gain or response** - the gain of a hearing aid measured in a standard 2 cc coupler, i.e., the coupler measurement of the hearing aid in dB minus the input signal level in dB.

**Target gain** - the prescribed real ear insertion gain or functional gain based in the individual's audiometric data and specific formulae or rules.

**Real ear unaided response (REUR)** - effects of the ear canal resonance and diffraction of the pinna and concha measured by a probe tube microphone at a point within the open external auditory canal. The REUR is the unoccluded ear canal measurement in dB minus the input signal level in dB.

**Real ear aided response (REAR)** - the gain of the hearing aid at the tympanic membrane, or the in situ gain. This is the aided frequency response, measured in dB SPL with a probe tube microphone at a point in the external auditory canal with the hearing aid in place. The input signal in dB is subtracted from the aided ear canal measurement in dB to obtain the REAR.

**Real ear insertion response (REIR)** - the approximate functional gain provided by a hearing aid. The REIR is the difference between the REAR and REUR measured at the same point in the ear canal with the same sound field. Schweitzer et al. (1990) indicated that the REIR is the net gain frequency response for the aided condition in relation to the unaided condition. The REIR is referred to as real ear insertion gain (REIG) when measured at specific frequencies.

**Real ear coupler difference (RECD)** - the difference between the frequency response of the hearing aid in the individual's ear and the 2 cc coupler response of the hearing aid. The RECD is the REAR minus the 2 cc coupler response in dB.

---

Using an insert earphone, Revit (1990) reported difference values between the occluded ear and 2 cc coupler measurements of approximately 3 dB at 500 Hz, 5 dB at 1 kHz, 9 dB at 1.5 kHz, 10 dB at 2 and 3 kHz, and 11 dB at 6 kHz (Revit, 1990). Since 2 cc coupler measurements differ from real ear measurements, these differences must be considered when specifying 2 cc coupler gain for ordering a hearing aid.

One way to accommodate real ear-coupler differences is to use correction factors. In 1980, Killion and Monser discussed the use of correction coupler curves and suggested the term Coupler Response for Flat Insertion Gain or Correction Figure (CORFIG). The CORFIG of a hearing aid predicts the frequency response of a hearing aid in a 2 cc coupler if the hearing aid produced a flat frequency response. As a correction factor, the CORFIG estimates the insertion gain provided to a user of that hearing aid by adding or subtracting a correction value from a coupler curve.

Determination of the CORFIG of a hearing aid depends upon several factors:

- 1) the type of sound field used and the orientation of the listener in the sound field;
- 2) the location of the microphone sound entrance on the head; 3) the construction of the earmold used to measure the in-the-ear and coupler response; and 4) the effect of individual differences in external ear canal resonance and ear canal and tympanic membrane impedance (Killion & Monser, 1980).

The angle of incidence of the sound source in the sound field is not important below 4000 Hz as frontal and random incidence response curves do not differ markedly up to that point (Shaw, 1980). At zero degrees incidence, however, the concha produces a sharp antiresonance at 8000 Hz which results in a notch in the CORFIG curve at that frequency (Shaw, 1980). In usual listening environments, reflected energy fills in the notch; in the sound field, a random-incidence sound source

will offset the concha antiresonance (Killion & Monser, 1980). Directional effects of the external ear are lost as the microphone is moved farther from the ear canal entrance. The type of sound field used, therefore, becomes less important the closer the microphone is to the ear canal entrance.

The earmold used to measure the in-the-ear and the coupler response must be identical or variations will result in the CORFIG correction. An earmold-coupler combination for 2 cc coupler measurements for ANSI standards consists of 2-mm diameter tubing leading into 3-mm diameter tubing. Most earmolds supplied with hearing aids, however, are of a constant bore resulting in a loss of high frequency response which must be added to the CORFIG correction curve (Killion & Monser, 1980).

Since the outer ear resonance and eardrum impedance vary with the individual ear, Killion and Monser (1980) suggested that a hearing aid designed for the average ear will display at least one deviation of perhaps 7 dB at any one given frequency. Each of the factors described above needs to be considered when using correction coupler curves.

Lybarger (1985b) also suggested that the use of correction values to estimate 2 cc coupler gain from insertion gain values is practical only if several factors are considered. First, acoustic connections from the hearing aid to the coupler and to the user's ear must be identical. If they differ, variations in the correction values will result. Second, corrections apply only to the closed coupler and earmold conditions as venting affects the low frequency response of a hearing aid. Lybarger (1985a) stated that the 2 cc coupler is unsatisfactory for measuring the effects of venting. Finally, correction values are only average values and may not account for individual

variability. Appropriate corrections are related to the type of hearing aid, since the location of the microphone entrance differs for behind-the-ear, in-the-ear, and in-the-canal aids (Lybarger & Teder, 1986).

Transforming insertion gain to 2 cc coupler gain values is often based on averaged real ear-to-coupler corrections (Punch et al., 1990). Mueller (1989) suggested that the averaged corrections may be supplied with a prescriptive formula, such as those included in the NAL Revised procedure (Byrne & Dillon, 1986), or may be chosen from one of several articles giving 2 cc coupler corrections. For example, Lybarger and Teder (1986) published calculated correction factors, from published data on transfer of sound from free field to the eardrum, and measured correction factors, obtained from coupler responses for flat insertion gain averaged from six laboratories. Punch et al. (1990) suggested that individual real ear-to-coupler gain corrections may differ considerably from corrections based on averaged real ear data. Differences as large as 23 dB between individual ear canals and 2 cc coupler measurements have been found (Nelson Barlow, Auslander, Rines, & Stelmachowicz, 1988). For the current investigation, the real ear-to-coupler correction is the real ear coupler difference (RECD).

### **REUR As A Correction Factor**

Correcting for the individual's ear canal and concha resonance when ordering a custom hearing aid may reduce the possibility of it being returned for modification of frequency response (Mueller, 1989). To make corrections for ear canal resonance the resonance of the individual's ear canal is measured with a probe tube microphone.



The difference between the individual resonance and the average ear canal resonance is then added to the desired coupler gain (Mueller, 1989).

Individualizing the ordering of custom hearing aids requires consideration of the individual's REUR. Byrne and Upfold (1990), however, suggested that when choosing a hearing aid to match desired target gain, the application of any correction value must be based on total real ear-to-coupler differences and not just the effect of ear canal resonance. RECD values reflect loss of ear canal resonance as well as other factors such as head diffraction, body-baffle, and differences in impedance between couplers and real ears, which are also important (Byrne & Upfold, 1990). The position of the hearing aid microphone on the wearer's head determines how sound reflected by the head and body is received by the microphone. A hearing aid gives a different response in a compliant ear canal than in a hard-walled coupler. These differences are reflected in the RECD.

Punch et al. (1990) have devised a method to convert real ear measurements to equivalent 2 cc coupler response value incorporating both the individual's REUR and RECD. They suggested that it is desirable to specify the desired response of the hearing aid to the manufacturer directly in terms of 2 cc coupler gain. This gives a common reference for the dispenser and the manufacturer in selecting and verifying the characteristics of the hearing aid (Punch et al., 1990).

### **Methods Of Specifying 2 cc Coupler Gain**

Desired 2 cc coupler gain can be specified to the manufacturer by several methods. A prescriptive formula such as the new procedure from the National Acoustic Laboratory (NAL Revised, 1986) can be used to designate the desired

insertion gain based on the individual's thresholds. The desired insertion gain is then converted to 2 cc coupler values by applying coupler corrections included with the formula. The NAL Revised procedure is based on a half gain rule for overall gain, a one-third slope rule for frequency response, and a frequency-dependent constant for the slope of a flat audiogram (Byrne & Dillon, 1986). The NAL Revised procedure calculates required 2 cc coupler gain as follows: a constant which is 0.05 times the combined thresholds of 500, 1000, and 2000 Hz is added to one-third of the threshold at each frequency; another constant specified for each frequency is then added as a correction factor for the conversion to 2 cc coupler gain. The NAL Revised procedure is used at the audiology clinic at Letterman Army Medical Center.

The prescriptive formula can be modified with information from the individual ear canal and concha. This modification is used in the Letterman clinic where corrections are made for the individual's REUR. Two cc coupler gain is calculated by adding the difference between the individual's REUR and average REUR values to the desired NAL target gain at each frequency. Average REUR values can be those used for the Knowles Electronics Mannequin for Acoustic Research (KEMAR) or those found by Shaw (1980).

The prescriptive formula can also be modified by incorporating the individual's REUR and RECD as described in the new Punch et al. (1990) formula. Punch and his colleagues contended that the actual real ear gain achieved depends upon the characteristics of the specific hearing aid and the individual ear canal. To determine an optimum fit, therefore, all available information should be used (Punch et al., 1990). The use of the Punch et al. method to order hearing aids requires the measurement of the frequency response of a behind-the-ear (BTE) hearing aid, first in a 2 cc coupler,

and then in a patient's ear using identical settings. The earmold used for this REAR measurement should be as similar as possible to the earmold or casing which will be required with the individual's BTE or ITE hearing aid. The REUR measurement is obtain and then the desired 2 cc coupler gain is determined using the formula:

$$\text{Target coupler gain} = \text{target REIG} - \text{RECD} + \text{REUR (Punch et al., 1990)}$$

### **Purpose Of This Investigation**

The question arises whether differences in methods of specifying 2 cc coupler gain to the manufacturer will result in different hearing aids provided for the same hearing loss. The purpose of this study was to determine whether the following three methods of specifying 2 cc coupler gain would prescribe similar gain for a given hearing loss. The three methods investigated were the NAL Revised prescriptive formula with the given 2 cc coupler corrections, the NAL Revised procedure with the 2 cc coupler corrections plus the REUR correction, and the Punch et al. (1990) formula incorporating the NAL Revised procedure with the individual's REUR and RECD in place of the NAL 2 cc coupler corrections. The following null hypothesis was presented: should the hearing loss remain the same, the three methods should prescribe similar gain for the hearing aid fitting.

## **CHAPTER II**

### **METHOD**

#### **Subjects**

Thirty-six patients who were fit with in-the-ear hearing aids at the Audiology Clinic at Letterman Army Medical Center were the subjects in this study. This resulted in forty-nine ears. These individual ears provided the external ear acoustics for REAR and REUR measurements; the degree of the individual's hearing loss was not important. A moderate to severe high-frequency sensorineural hearing loss was simulated to provide a basis for determining desired insertion gain for each of the three methods. Table 2 presents this simulated hearing loss and the desired NAL 2 cc coupler gain (without reserve gain) calculated for the hearing loss.

#### **Apparatus**

Real ear measurements for this study were taken with a Madsen Electronics IGO 1500 Insertion Gain Optimizer using a pressure method. Madsen (1986) described the pressure method as one in which the input sound pressure level is controlled by a pressure-calibrated reference microphone located close to the entry of the hearing aid microphone. A frequency modulated tone sweep at 60 dB SPL was used to make the real ear measurements. Two cc coupler measurements were taken in a Frye Electronic Inc. Fonix FC5010 Sound Chamber. The hearing aids used for this

**Table 2. Simulated hearing loss and the desired NAL 2 cc coupler gain (without reserve gain) calculated for the hearing loss.**

	Frequency in kHz						
	0.5	1.0	1.5	2.0	2.5	3.0	4.0
Thresholds							
in dB HL	35	40	55	60	70	75	75
Desired NAL 2 cc							
coupler gain	12	20	23	25	29	30	28

investigation were Argosy, Qualitone, and Siemens in-the-ear (ITE) hearing aids which had been fit to each patient. Vents in the hearing aids ranged in size from large to pressure vents.

### **Procedure**

A staff audiologist and an audiology intern recorded the REUR and REAR measurements for each patient using the in-the-ear hearing aid which had been fit for that patient's ear. The probe tube position was identical for both aided and unaided measurements (Hawkins & Mueller, 1986). The probe tube was placed 5 mm beyond the tip of the hearing aid as suggested by Burkhard and Sachs (1977).

The 2 cc coupler response of the hearing aid was measured in the Fonix Sound Chamber with the volume control setting in the identical position as for the REAR measurement. Vents in the hearing aid were plugged for the 2 cc coupler measurements.

The following calculations were made. The NAL Revised procedure was used to calculate the desired NAL 2 cc coupler gain for the simulated hearing loss presented in Table 2. No reserve gain was added. For each patient, the REAR minus the 2 cc coupler response yielded the real ear-to-coupler difference (RECD).

Table 3 presents the values found by Shaw (1980) for the average response of an unoccluded ear. To make the REUR corrections, Shaw's average resonance at each frequency was subtracted from the individual's REUR. This difference was then added to the NAL target coupler gain to obtain the desired 2 cc coupler gain for the NAL plus REUR corrections method. No reserve gain was added.

To obtain the desired 2 cc coupler gain for the Punch et al. formula, the patient's REUR was added to the NAL target gain without the 2 cc coupler corrections. The patient's RECD was then subtracted to obtain the desired coupler gain (Punch et al., 1990). No reserve gain was added.

Deviations of the NAL plus REUR corrections method and the Punch et al. formula from the NAL Revised procedure were determined. Means and standard deviations of the individual data were also calculated.

**Table 3. Average resonance values of unoccluded ear (Shaw, 1980)**

	Frequency in kHz						
	0.5	1.0	1.5	2.0	2.5	3.0	4.0
Response values							
in dB	1	2	6	12	16	15	14



## CHAPTER III

### RESULTS

This study investigated whether three methods of specifying 2 cc coupler gain, the revised NAL Revised procedure (1986), the NAL + REUR corrections method, and the Punch et al. formula (1990), would prescribe similar gain across frequencies for a given hearing loss. Figures 1 to 7 show the deviation of the NAL + REUR corrections method and the Punch et al. formula from the prescribed NAL 2 cc coupler gain at each frequency.

Figure 1 shows that at 500 Hz all scores from the NAL + REUR formula varied from the NAL desired 2 cc coupler gain by only 2 dB. Using the Punch et al. formula, forty-four (90%) of the hearing aids gave gain greater than 2 dB above the NAL desired coupler gain.

At 1000 Hz, shown in Figure 2, all of the scores from the NAL + REUR formula were equal to or 6 dB below the desired NAL coupler gain. The Punch et al. formula had thirty (61%) hearing aids equal to or greater than the NAL coupler gain by up to 10 dB.

Figure 3 shows that at 1500 Hz forty-eight (98%) of the hearing aids ordered by the NAL + REUR formula fell within the range of 6 dB above and below the NAL coupler gain. Thirty (61%) of those gave gain equal to the NAL desired coupler gain. At 1500 Hz, the Punch et al. formula ordered thirty-six (73%) hearing aids within the

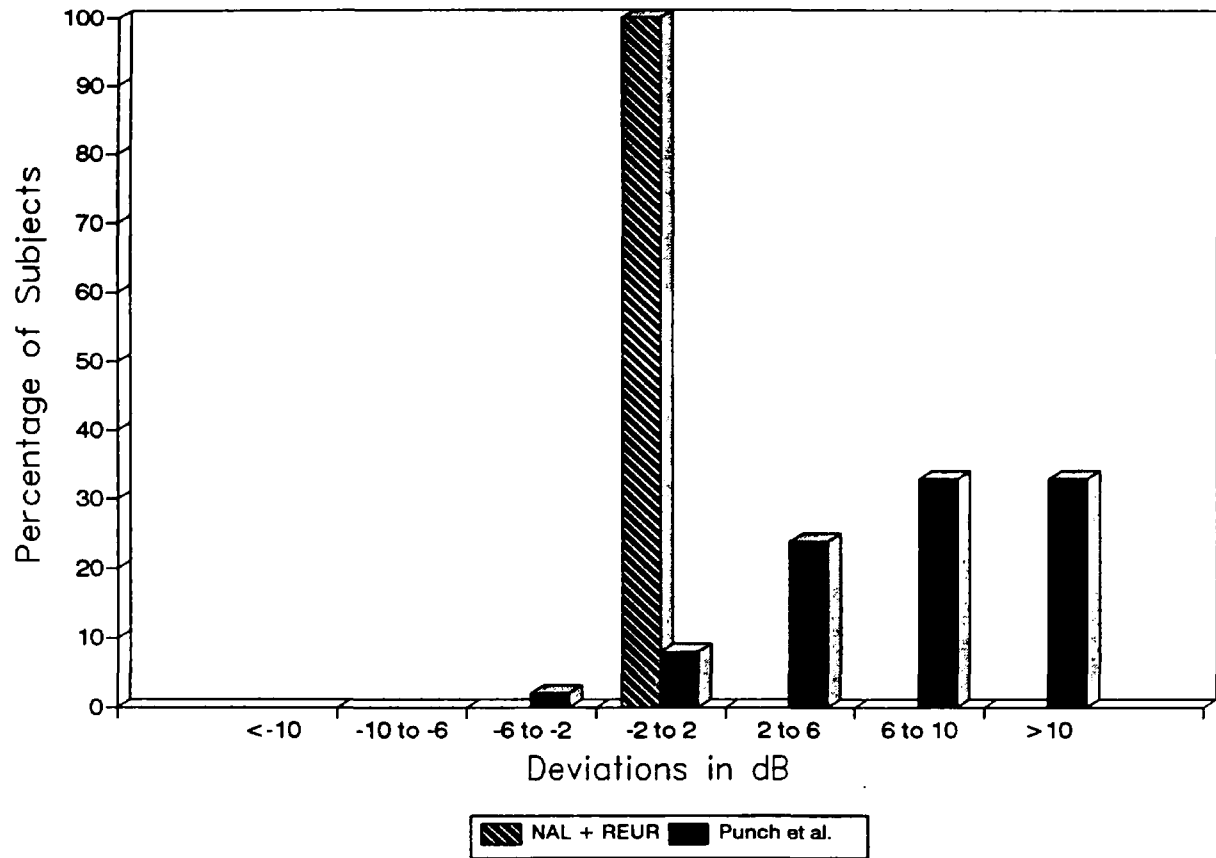


Figure 1. Deviations from the NAL desired 2 cc coupler gain by the NAL + REUR corrections method and the Punch et al., (1990) formula at 500 Hz.

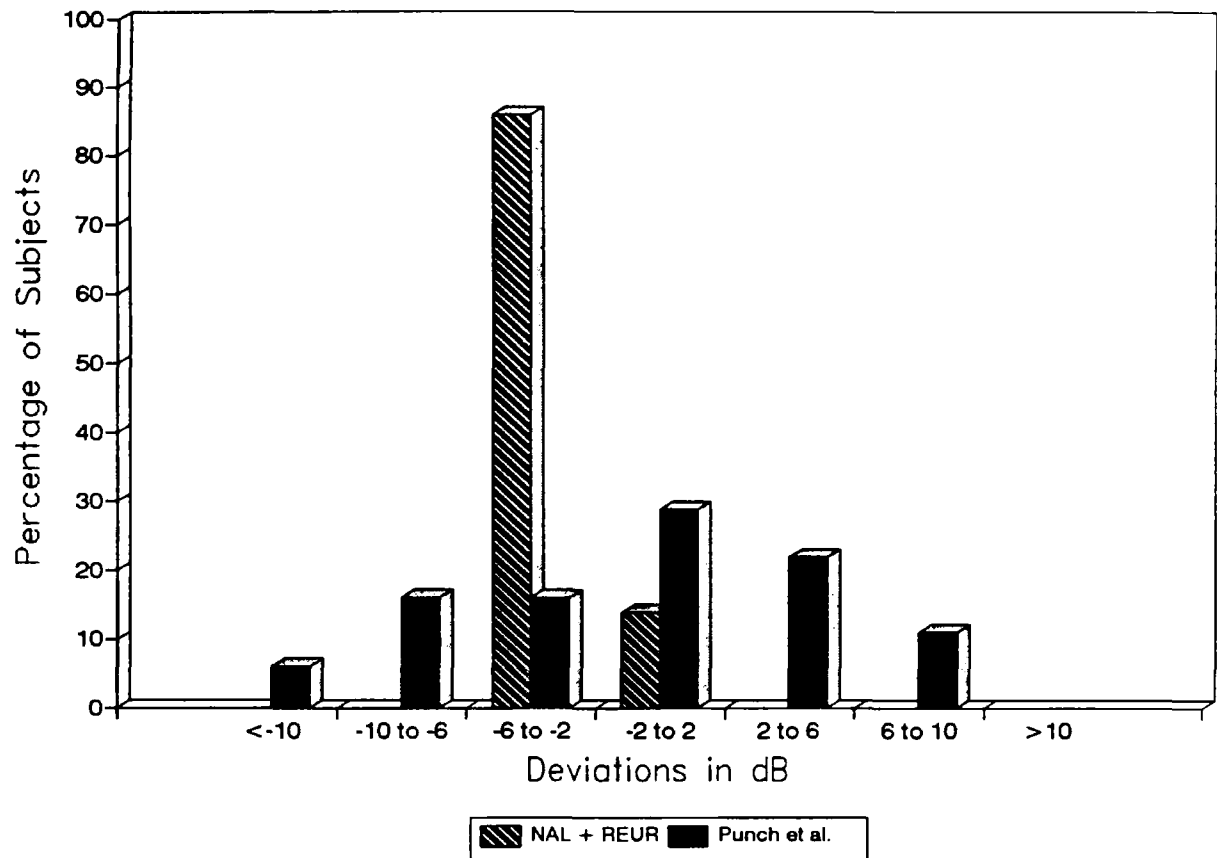


Figure 2. Deviations from the NAL desired 2 cc coupler gain by the NAL + REUR corrections method and the Punch et al. (1990) formula at 1000 Hz.

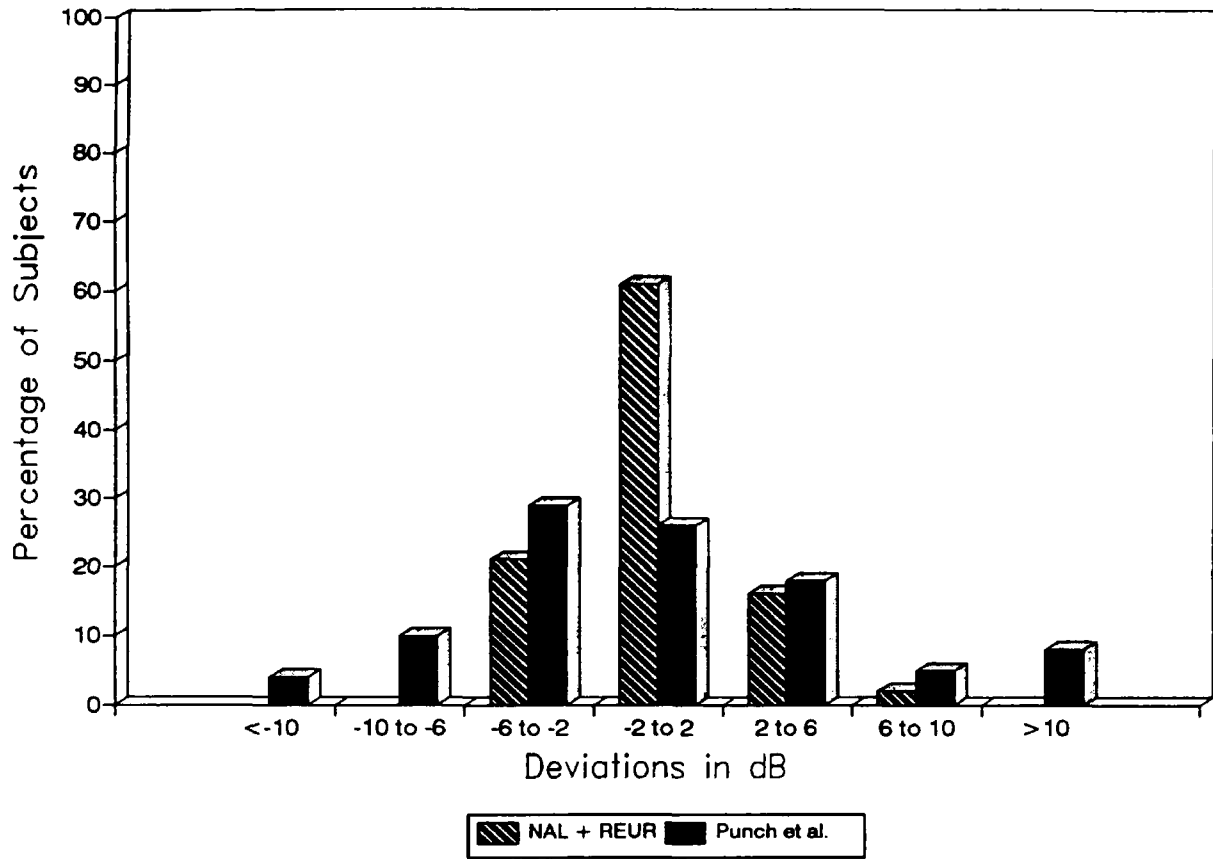


Figure 3. Deviations from the NAL desired 2 cc coupler gain by the NAL + REUR corrections method and the Punch et al. (1990) formula at 1500 Hz.

same range. Of these twenty-six (53%) hearing aids had gain equivalent to the NAL desired coupler gain.

At 2000 Hz, shown in Figure 4, twenty-five (25%) of the NAL + REUR corrections method hearing aids had gain equivalent to the NAL hearing aids while twenty-one (43%) had gain less than the NAL prescribed coupler gain. The Punch et al. formula prescribed coupler gain equal to the NAL gain for eleven (22%) hearing aids at 2000 Hz while twenty-seven (56%) hearing aids had gain greater than the NAL desired coupler gain.

Figure 5 shows that at 2500 Hz thirty-six (74%) of the NAL + REUR method hearing aids had within 2 and 10 dB less than the desired NAL coupler gain and that none had more gain than the NAL prescription. Eleven (22%) of the hearing aids had gain equivalent to the NAL prescription. Using the Punch et al. formula, thirty-two (66%) of the hearing aids had more coupler gain than that required by the NAL formula and fourteen (28%) had equivalent gain.

At 3000 Hz, as shown in Figure 6, twenty (41%) of the NAL + REUR hearing aids had gain equivalent to the NAL coupler gain and twenty-two (45%) of them had less gain. At this frequency, seven (14%) hearing aids had gain greater than the NAL prescription. Most of the hearing aids fit by the Punch et al. (1990) formula (20 hearing aids or 41%) had 2 to 6 dB of gain more than the NAL prescription. Ten (20%) of the hearing aids fit by this same formula had gain equal to that of the NAL formula and sixteen (32%) had more than 6 dB greater gain.

At 4000 Hz, shown in Figure 7, the NAL + REUR method gave results opposite to those of the Punch et al. formula. Thirty-one (64%) of the NAL + REUR hearing aids had gain equal to or 6 dB below the NAL prescribed coupler gain whereas the

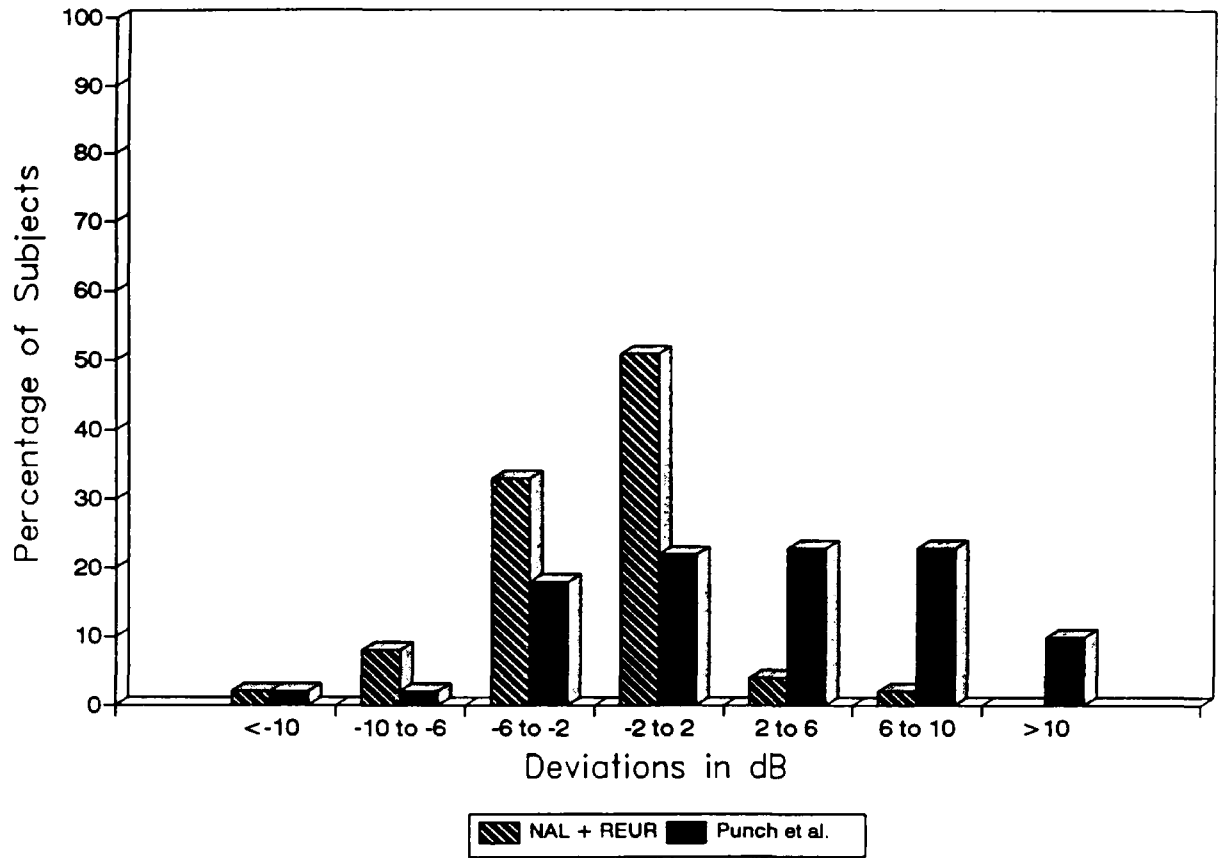


Figure 4. Deviations from the NAL desired 2 cc coupler gain by the NAL + REUR corrections method and the Punch et al. (1990) formula at 2000 Hz.

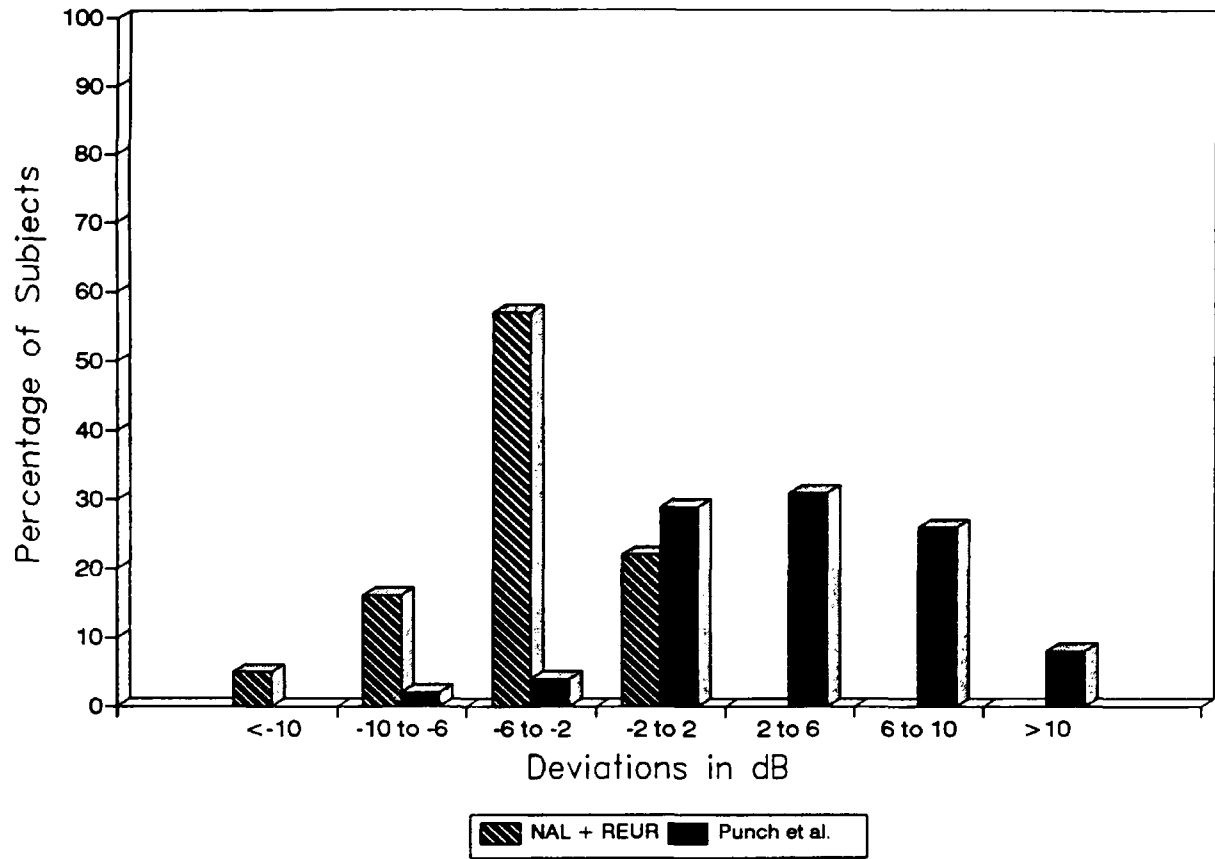


Figure 5. Deviations from the NAL desired 2 cc coupler gain by the NAL + REUR corrections method and the Punch et al. (1990) formula at 2500 Hz.

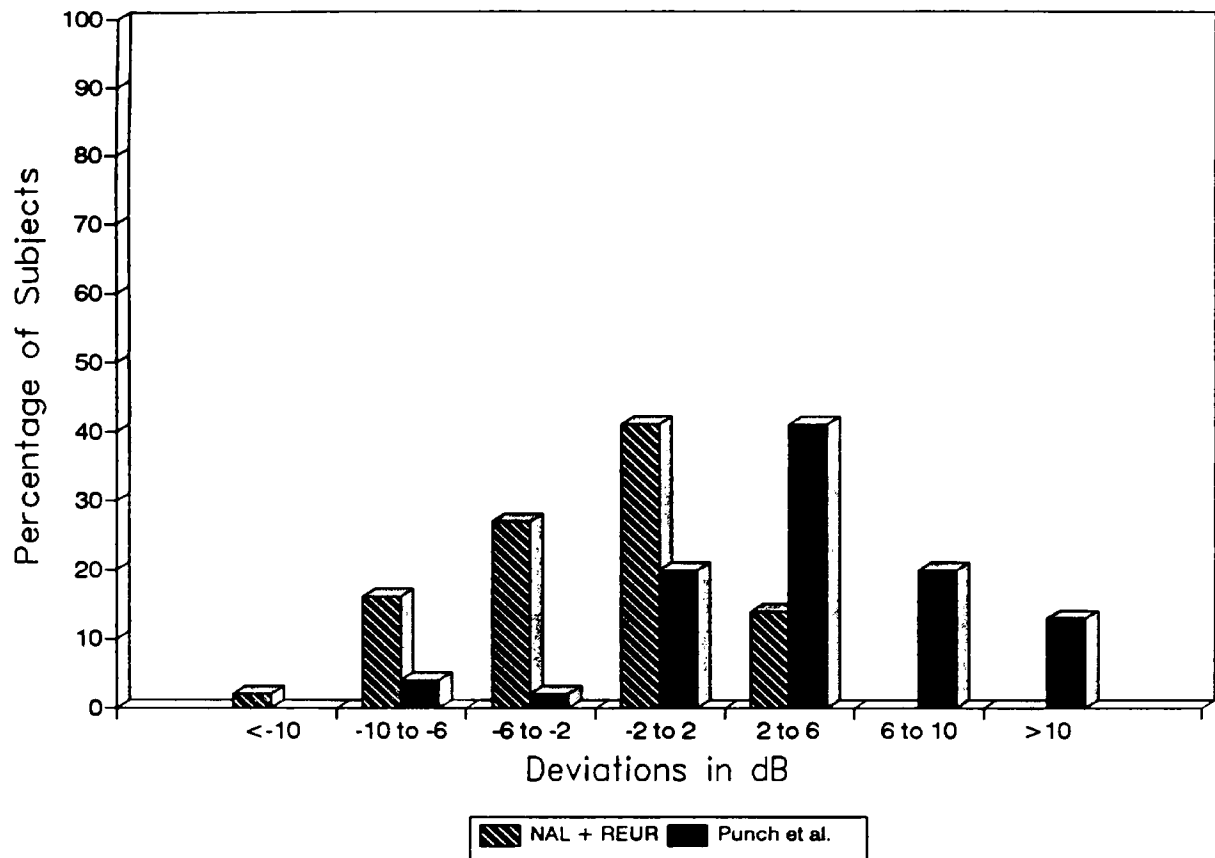


Figure 6. Deviations from the NAL desired 2 cc coupler gain by the NAL + REUR corrections method and the Punch et al. (1990) formula at 3000 Hz.



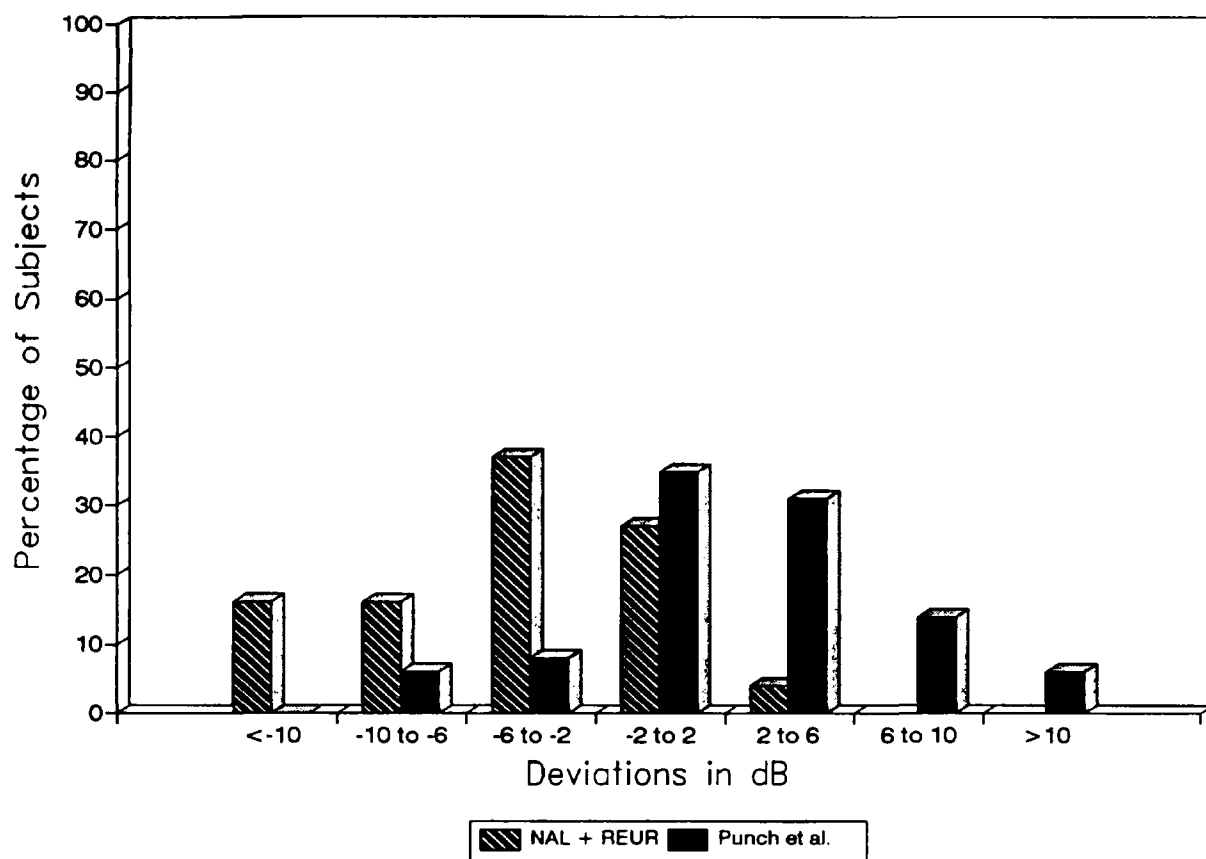


Figure 7. Deviations from the NAL desired 2 cc coupler gain by the NAL + REUR corrections method and the Punch et al. (1990) formula at 4000 Hz.

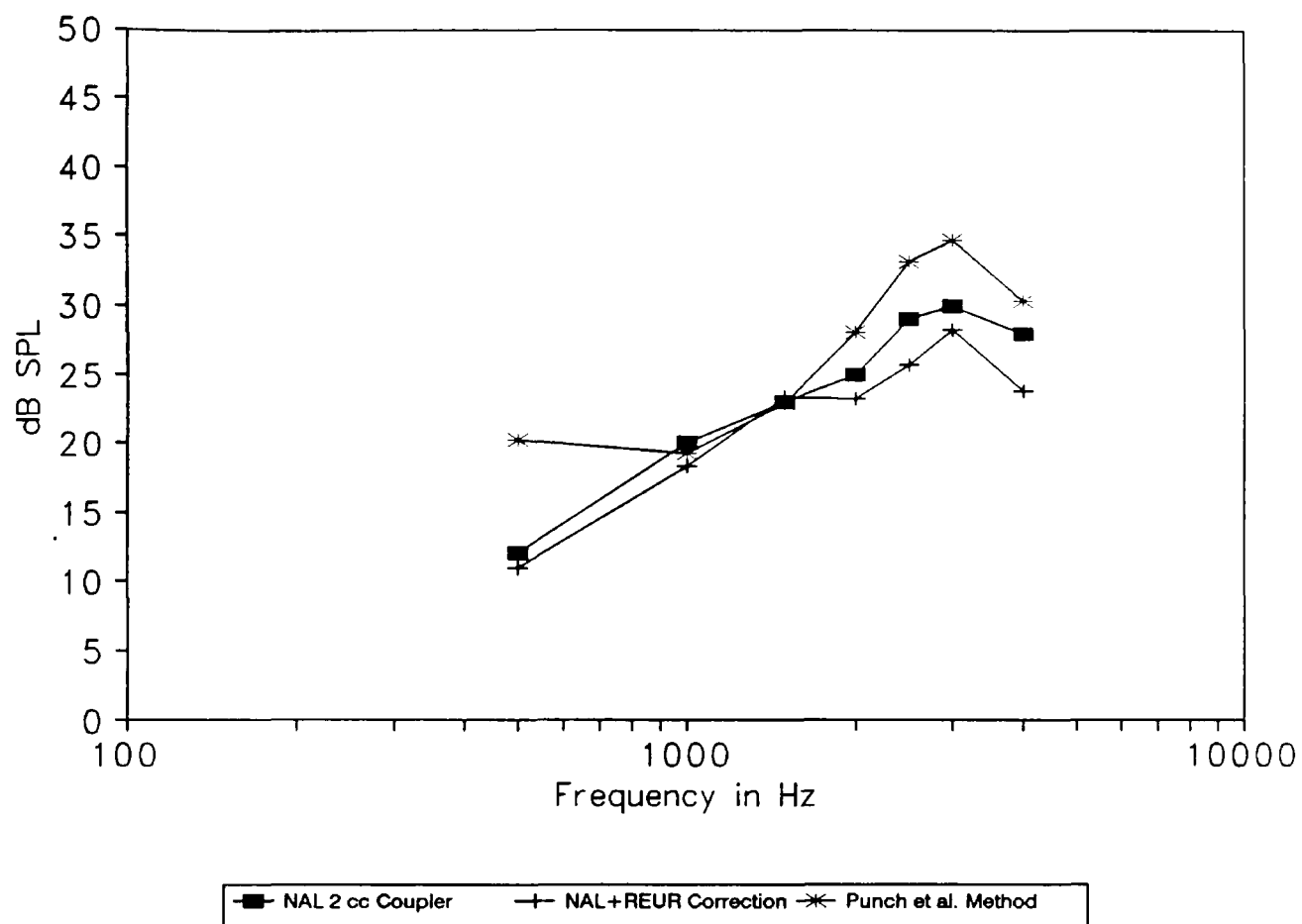


Figure 8. Desired 2 cc coupler gain specified by three different methods for the same hearing loss.

same number of Punch et al. hearing aids had gain equal to or 6 dB greater than the NAL prescribed gain. Sixteen (32%) hearing aids ordered by the NAL + REUR method had more than 6 dB less gain than the NAL prescription and ten (20%) hearing aids ordered by the Punch et al. formula had more than 6 dB greater gain than NAL.

Figure 8 shows that the means of the three methods showed the same trends as the bar graphs of deviations. The NAL + REUR method shows less prescribed coupler gain than the NAL Revised procedure and the Punch et al. formula shows more prescribed gain than NAL. The three methods were in closest agreement at 1500 Hz.

The use of t-tests determined whether 2 cc coupler gain prescribed by the NAL + REUR corrections method and the Punch et al. formula varied significantly from the NAL prescribed 2 cc coupler gain. The results indicated that the NAL + REUR method was significantly different from the NAL procedure at 1000 Hz ( $t=15.87$ ;  $p < .05$ ), 2000 Hz ( $t=3.72$ ;  $p < .05$ ), 2500 Hz ( $t=8.71$ ;  $p < .05$ ), 3000 Hz ( $t=2.98$ ;  $p < .05$ ), and 4000 Hz ( $t=6.50$ ;  $p < .05$ ). The Punch et al. formula differed significantly from the NAL procedure at 500 Hz ( $t=12.42$ ;  $p < .05$ ), 2000 Hz ( $t=3.86$ ;  $p < .05$ ), 2500 Hz ( $t=6.41$ ;  $p < .05$ ), 3000 Hz ( $t=7.23$ ;  $p < .05$ ), and 4000 Hz ( $t=3.76$ ;  $p < .05$ ). Neither method varied significantly at 1500 Hz.

T-tests were also used to determine if 2 cc coupler gain prescribed by the Punch et al. formula differed significantly from that prescribed by the NAL + REUR corrections method. The two methods differed significantly at 500 Hz [ $t(47)=16.13$ ;  $p < .05$ ], 2000 Hz [ $t(47)=7.35$ ;  $p < .05$ ], 2500 [ $t(47)=10.93$ ;  $p < .05$ ], 3000 Hz [ $t(47)=7.81$ ;  $p < .05$ ], and 4000 Hz [ $t(47)=7.91$ ;  $p < .05$ ]. The two methods did not vary significantly at 1000 and 1500 Hz.

The mean ear canal resonance (REUR) for the forty-nine ears in this study was compared with that of the Knowles Electronics Mannequin for Acoustic Research (KEMAR) and the resonance for ear canals determined by Shaw (1980). Figure 9 presents this comparison. The REUR for the current investigation peaked at 3000 Hz as does that of KEMAR. The Shaw REUR peaks at 2500 Hz. In the frequencies below 1500 Hz the average REUR was greater than the KEMAR values and less than the Shaw data. At frequencies greater than 2000 Hz, the average REUR was less than KEMAR and Shaw's values, although the KEMAR and Shaw values were within one standard deviation of this REUR.

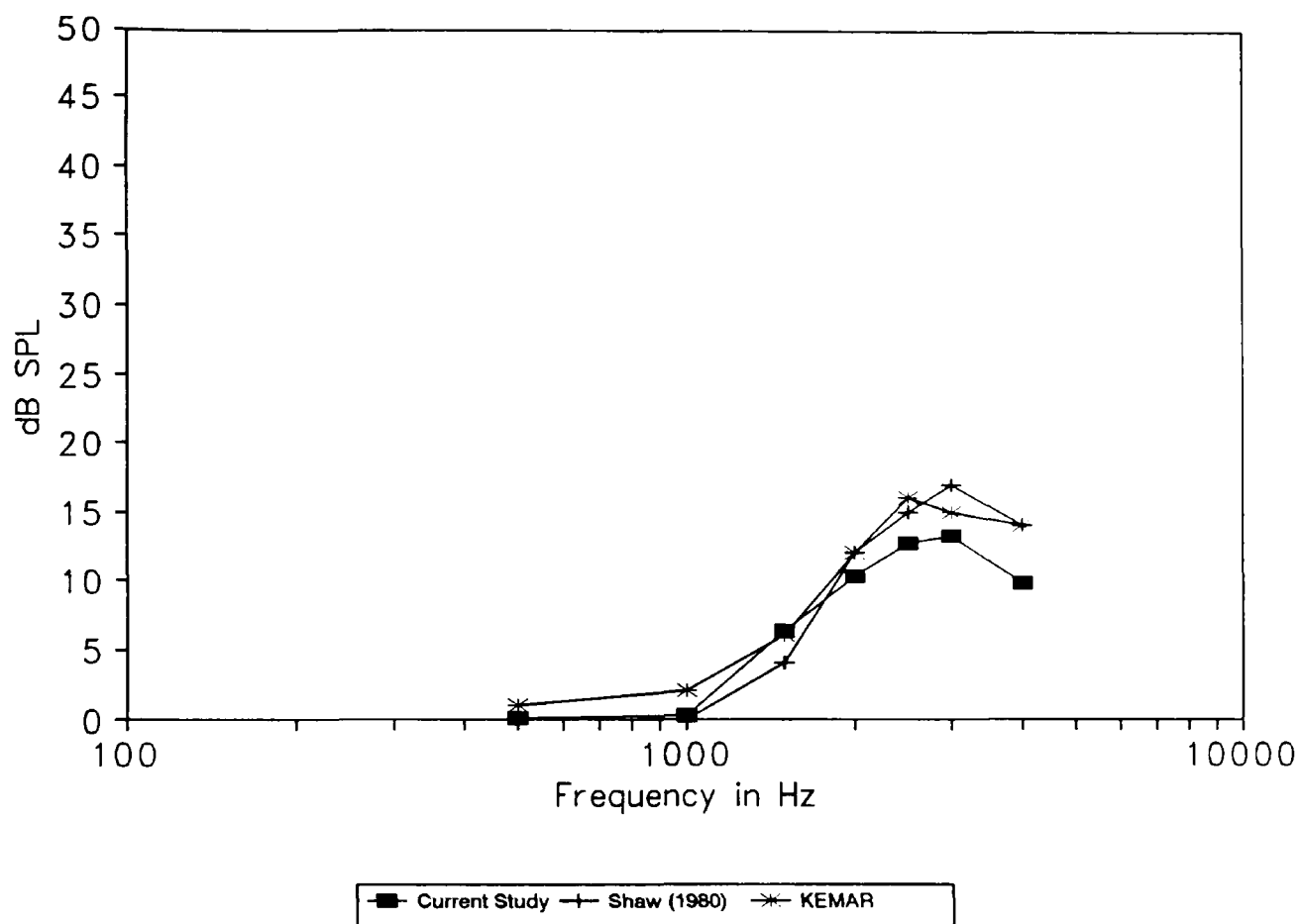


Figure 9. A comparison of average real ear canal resonances (REUR's) found in the current study and those found by Shaw (1980) with those used for KEMAR.

## CHAPTER IV

### DISCUSSION

The results of the current study indicated that each of the three methods compared -- the NAL Revised procedure, the NAL + REUR corrections method, and the Punch et al. formula -- prescribed different 2 cc coupler gain across frequencies for a given hearing loss. The NAL + REUR correction method prescribed less gain than the desired NAL target 2 cc coupler gain. The Punch et al. formula prescribed more gain than the NAL target coupler gain at all frequencies but 1000 and 1500 Hz. All three methods prescribed the same gain at 1500 Hz.

Killion and Monser (1980) and Lybarger (1985) stated that the use of correction or CORFIG values depends on such factors as the incidence of the sound source, location of the hearing aid microphone, construction of the coupling system, use of closed earmold/coupling conditions, and variability in resonance of individual ear canals and conchas. This investigation attempted to account for all of these factors. The current study used a probe tube microphone system and the pressure method to take real ear measurements. Having the reference microphone placed in close proximity to the entry of the hearing aid microphone may eliminate the diffraction effects of the head and body on the hearing aid's performance characteristics (Madsen, 1986). A real time equalization method such as the pressure method has been reported to stabilize the sound field across time and thus may compensate for any

ambient noise or patient movement (Preeves, 1987). The use of warble tones as stimulus may produce diffuse sound reflections in the environment which, in turn, would help maintain a constant sound pressure level. The same in-the-ear hearing aid used for REAR and 2 cc coupler measurements assured that a nearly identical coupling system was used across both measurements. The adoption of the NAL + REUR method and the Punch et al. formula may be able to account for some of the variation in individual ear canal resonances and tympanic membrane impedances by applying them as correction factors in prescribing the 2 cc coupler gain. The only condition for the use of correction factors which the current study did not meet was the condition pertaining to closed earmolds.

### **Effects of Venting**

Venting causes a reduction in the low frequency response of a hearing aid (Lybarger, 1985a). Many patients in the current study had high frequency hearing losses with essentially normal hearing sensitivity in the low frequencies. Although this study did not use hearing aids with IROS vents, many of the hearing aids investigated had vents to accommodate the normal hearing sensitivity in the low frequencies. A study by Austin, Kasten, and Wilson (1990) concurred with Lybarger (1985a) that the 2 cc coupler is unsatisfactory for measuring the effects of vents. The results of the current study showed different frequency responses for the hearing aid in the real ear and in the 2 cc coupler. Some of these differences may have been due to the effects of venting, particularly at 500 and 1000 Hz where negative RECD's resulted.

The vents of all hearing aids were plugged for the 2 cc coupler measurements but not for the REAR measurements. Real ear aided response (REAR) measurements for a vented hearing aid showed less gain in the low frequencies than the same hearing aid with plugged vents in the 2 cc coupler. A negative RECD resulted when the 2 cc coupler response was subtracted from the REAR. Figure 10 shows the negative mean RECD at 500 and 1000 Hz found in this investigation. Adding a negative RECD in the Punch et al. formula prescribed more gain at 500 Hz as indicated by Figure 8. Different results may have occurred if the simulated hearing loss had indicated normal hearing sensitivity in the low frequencies, although this would not have affected the negative RECD's. Perhaps negative RECD's should be converted to zero as is done with negative gain when it appears in the NAL Revised procedure (Byrne & Dillon, 1986). Further research is required on the effects of venting in real ear measurements.

The average real ear-to-coupler difference (RECD) calculated for this investigation was compared with those found by Sachs and Burkhard (in Killion & Monser, 1980), Nelson Barlow et al. (1988), and Revit (1990). Generally the data in this study agreed with the average RECD's found in those other studies except at 500 Hz where less gain was indicated, perhaps as a result of the vented hearing aids. Given this agreement with other RECD studies, the results of the Punch et al. formula using the RECD would appear to be reasonable; there is as yet no other available research on the application of the Punch et al. formula.



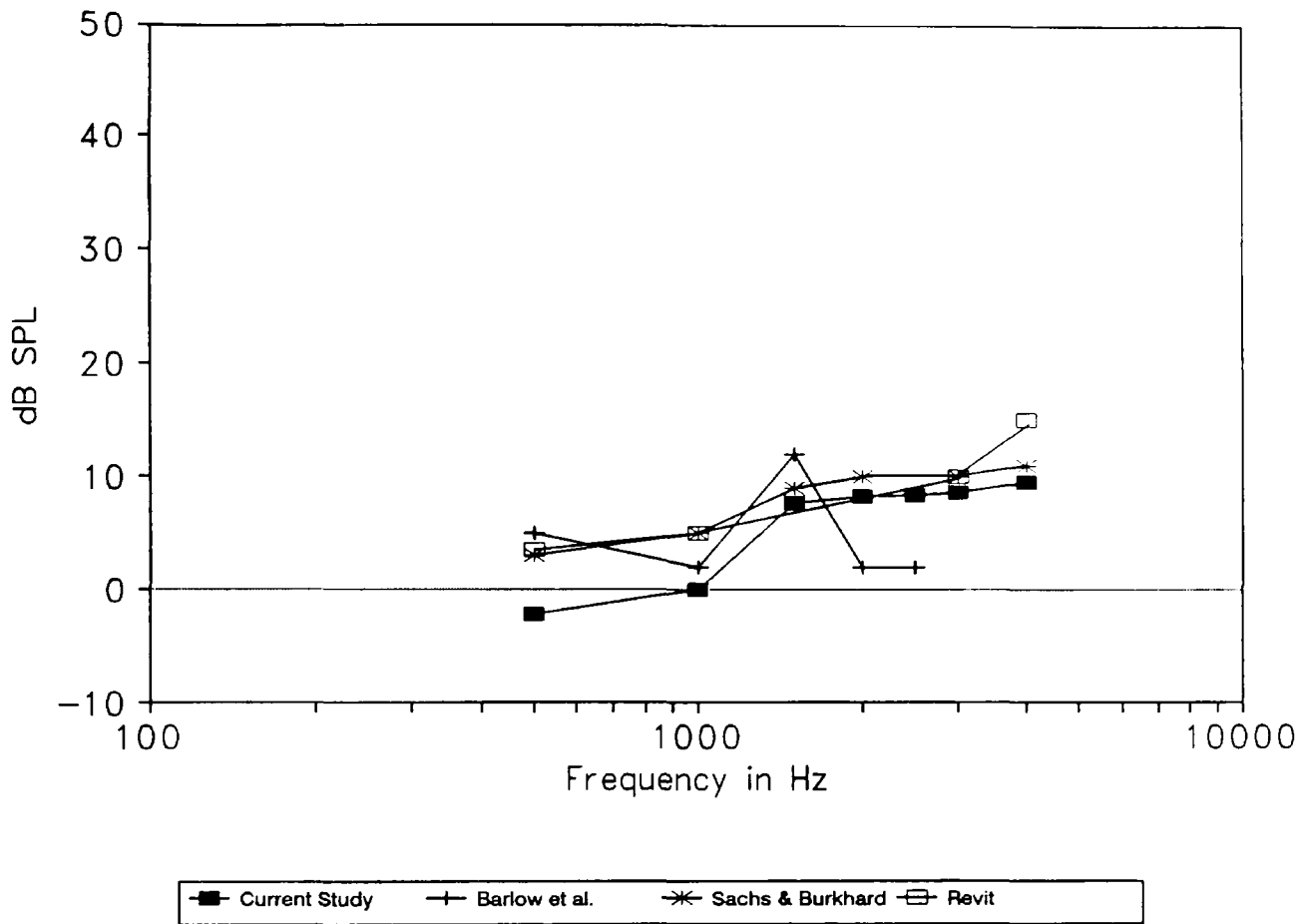


Figure 10. A comparison of real ear coupler differences (RECD's) found in the current study and those found by Sachs and Burkhard (1972), Nelson Barlow et al. (1988), and Revit (1990).

## **Clinical Implications**

This current investigation suggested that the Punch et al. method of specifying 2 cc coupler gain prescribes more gain in the high frequencies than either the NAL Revised procedure or the NAL with REUR corrections. Byrne (1987) stated that for sloping high frequency hearing losses, the prescribed gain at 4000 Hz and perhaps at 3000 Hz may differ among prescriptive formulae but these differences may not occur when the hearing aid is measured in the real ear. When the hearing aid achieves the prescribed gain at the mid frequencies, it is nearly always giving the maximum gain at 4000 Hz that is technically possible from that hearing aid, regardless of the prescriptive formula used. Research is required to determine if hearing aids ordered by the Punch et al. method can provide the required gain in the higher frequencies.

## **Future Research**

Further research is required on the practical application of the Punch et al. formula. If the formula prescribes more gain in the higher frequencies, there may be problems with feedback or over-amplification of the mid frequencies. Punch and his colleagues used the RECD as a 2 cc coupler conversion factor. Other studies may show that it can be used similarly in other prescriptive formulae. Further, if additional research indicates a correlation between an individual's REUR and RECD, the RECD may be used without the REUR in prescriptive formulae. The RECD may be a realistic 2 cc coupler conversion factor as it gives an indication of how a particular hearing aid performs in an individual's ear and in the 2 cc coupler.

### **Importance of Specifying 2 cc Coupler Gain**

Punch et al. (1990) suggested that converting real ear measurements to equivalent 2 cc coupler response values gives the dispenser a means of specifying the desired response of the hearing aid directly to the manufacturer. This information stated in terms of 2 cc coupler gain gives the dispenser and the manufacturer a common reference to specify and evaluate the hearing aid. Incorporating the individual's ear canal acoustics into the specification of 2 cc coupler gain can produce the most appropriate real ear insertion gain for that individual (Punch et al., 1990).

It is possible to use 2 cc coupler response values to specify and verify electroacoustic characteristics of a hearing aid. It is also possible to individualize those values for each patient. The onus is on the hearing instrument dispenser to determine which method of specifying 2 cc coupler gain will provide the most appropriate gain for the patient's hearing loss. This should result in fewer hearing aid returns and greater customer satisfaction.

### **Summary**

Nearly 80% of hearing aids now dispensed are custom in-the-ear hearing aids. A satisfactory method of specifying the desired electroacoustic characteristics for these hearing aids to the manufacturer is required. Thirty-six patients fit with forty-nine in-the-ear hearing aids at Letterman Army Medical Center, San Francisco, participated in this study to determine whether three different methods of specifying 2 cc coupler gain to the manufacturer would prescribe similar gain across frequencies for a given hearing loss. The three methods compared and investigated were the NAL Revised procedure, a NAL + REUR corrections method, and a new formula described by

Punch et al. (1990) which incorporated use of the individual's REUR and RECD. The results of this study indicated that the NAL + REUR corrections method prescribed less gain than either of the two other methods. The Punch et al. formula prescribed more gain than either of the two other methods, particularly in the high frequencies.

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